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To cite this article: A S Shmygalev *et al* 2019 *J. Phys.: Conf. Ser.* **1421** 012049

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Infrared fiber based on AgCl-AgBr and AgBr-TlI crystals to transfer thermal radiation in pulsed

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Abstract. The our research objective is to study IR energy transfer in pulsed and continuous mode through optical fibers produced from crystals of silver halide and a monovalent thallium solid solutions. It is assumed that the transfer of infrared radiation in the pulsed mode will significantly reduce losses. We designed the experimental setup, determined its operational parameters, and obtained the dependence of the detector's received radiation on the frequency of the pulses of thermal radiation. As a research subjects we used two different fibers compositions namely $\text{AgCl}_{0.25}\text{Br}_{0.75}$ and $\text{Ag}_{0.95}\text{Tl}_{0.05}\text{Br}_{0.95}\text{I}_{0.05}$.

1. Introduction

The temperature of a heated body can be measured using the properties of optical fibers based on solid solutions of silver halides and monovalent thallium (AgBr-TlI and AgCl-AgBr) [1] to receive and transmit radiation from heated bodies to sensors. Temperature determination by a noncontact method is based on this principle. Since in most applications infrared fiber receive radiation from bodies whose temperature is higher than the ambient temperature, in the establishment of thermal equilibrium, part of the transmitted wave energy (in the form of thermal energy) is lost. These losses [2] are especially critical in the case of IR optical fibers for noncontact temperature measurement, since they can cause significant errors due to parasitic radiation from a source, receiver noise and thermal properties of fiber material [3]. It should be noted that the radiation power of real heated bodies is very small. Thus, for example, energy luminosity of the body heated to 100 °C will be in the range $10^{-3} - 10^{-4}$ (W·m). Thus, the presence of even minor errors significantly complicates the signal processing. When using amplifiers of an optical signal (for example, lenses), there is also an increase in noise, which in turn substantially increases the errors.

One of the options for reducing errors and increasing the incoming signal can be the use of a pulsed mode of transferring thermal energy. This mode is used in laser technology, however, the laser beam has a much higher power and radiation density, therefore, the influence of the thermophysical properties of the material is small, in contrast to low-power radiation. In this connection, it becomes necessary to estimate the parameters of the pulsed mode at low input signal power from bodies emitting in the middle infrared wavelength range. In this paper, we are given a study to identify a



transmission opportunity of thermal radiation in pulsed and continuous modes through the IR optical fiber based on AgBr-TII and AgCl-AgBr crystal systems.

2. Experimental setup

To study transmission of the thermal radiation in the pulsed mode using an optical fiber, an optoelectronic system was designed and constructed, the scheme of which is shown in figure 1.

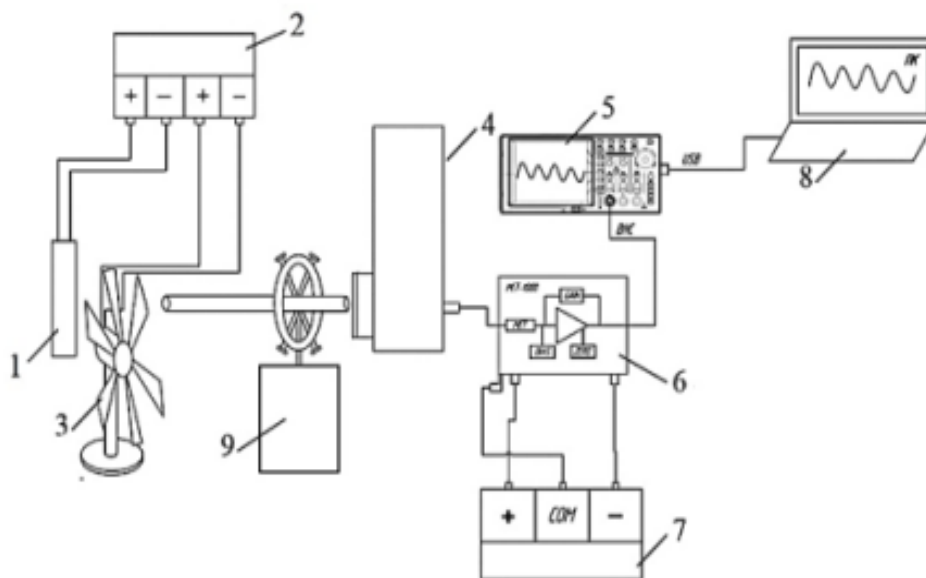


Figure 1. The scheme of optoelectronic system: 1 – Peltier’s element, 2 – two-channel power supply unit, 3 – rotating shading obstruction impeller (modulator), 4 – MCT-detector, 5 – oscilloscope, 6 – operational amplifier, 7 – current source, 8 – PC, 9 – optical fiber in a special bracket.

The Peltier’s element (1) was the source of thermal radiation and connected to the two-channel power supply unit Instek PPE-3323 (2) with a current strength of $U = 3.3$ V. Adjusting the voltage parameters on the power supply allowed to change the surface temperature of the hot side of the Peltier’s element in the range from 290 to 400 K (measured by the thermal imager Testo 882).

The temperature range is comparable to a wavelength of about from 7 to 9 microns. Infrared radiation was transmitted directly to the cadmium-mercury-tellurium (MCT) detector (4) MCT-13.100 from InfraRed Inc., cooled by liquid nitrogen. MCT detector was working in the photoconductive mode with "dark" resistance of 35 ohms, the resistance detector operating range was in the range 20 - 100 ohms and the spectral region of measurement was 2 - 13 microns. The resistance of the detector in these experiments was 28-35 Ohm (with IR irradiation with a wavelength of 7-8 μm). The detector was connected to the operational amplifier (op-amp) (6) MST-1000 from InfraRed Inc., whose working in frequency range from 1.5 to 170 Hz at noise level $4 \cdot 10^{-10}$ ($\text{W} \cdot \text{Hz}^{-1/2}$). The signal from the amplifier output was directed to the oscilloscope (5) Owon PDS 5022S, which displayed a graph of the change in the output voltage in time, and automatically measured the signal parameters. The graphs from the oscilloscope were transferred to the PC (8) and later processed using the software Oscilloscope PC suite (version 2.0.8.11).

To create a pulsed mode of the IR radiation transmission, a rotating shading obstruction impeller (modulator) was used (3). The impeller was attached to a low power drive with a starting voltage of 1 V and an operating voltage in the range from 0.6 V to 3.5 V, at which the speed range varied from 20 to 170 Hz. The rotational speed of the modulator was determined by the ST-5 stroboscope. Optical

fiber (9) was placed between the impeller and the receiver to study the transfer of heat radiation in a pulsed mode.

3. Characterizations of the experimental setup

The influence of the pulsed operating mode on the perceiving power of the MCT detector is interesting from the viewpoint of the physical properties of the photocell itself, namely, the processes of generation and recombination of charge carriers. Generation-the production of free electrons-occurs under the action of photons whose energy exceeds the width of the forbidden band of the photocell material and is sufficient to form an electron-hole pair. Recombination is the reverse of the generation process and involves returning the electron to the valence band. In the process of recombination, energy is released equal to the difference between the initial and final energy states of the electron. The nature of energy release is one of the criteria for classifying recombination processes.

In the MCT detector, Auger recombination of carriers takes place, at which energy is transferred to the third particle when the main carrier returns to its valence band. So the recombination process has a longer duration and energy intensity than recombination of the "zone-zone" type. Pulsed mode of operation allows the MCT-element to take portions of the energy of the source, while the generation process lasts a longer time, as a result of which a deeper decrease in the detector's resistance occurs, which means that the voltage output from the op-amp is increased. There is a similar process with recombination, the inverse of generation, i.e. there is a gradual increase in resistance, accompanied by a voltage drop on the amplifier. The dependence of the generation and recombination processes on the increase in the pulse frequency is non-linear, and therefore the dependence investigation and analysis should be performed for continuous and pulsed operation.

To estimate the operation characteristics of the MCT detector in the continuous and pulsed modes, the characteristics of the output voltage versus time were investigated without a special heat radiation source and with a Peltier's element as a source at a temperature of 350 K and a pulse frequency of 60 Hz. Sources of thermal radiation do not affect the characteristic of the output voltage in a continuous mode, and the amplitude of the oscillations is constant in time and has a noise character with a maximum value of 0.8 mV. Figure 2 shows the variation of the output voltage U_{out} on the op-amp in time τ under the pulsed mode of irradiation of the detector. In this case, the output voltage characteristic is in the form of a pseudo-sinusoid with a pulse frequency corresponding to the modulator frequency, and the output voltage correlates with the temperature of the heat source.

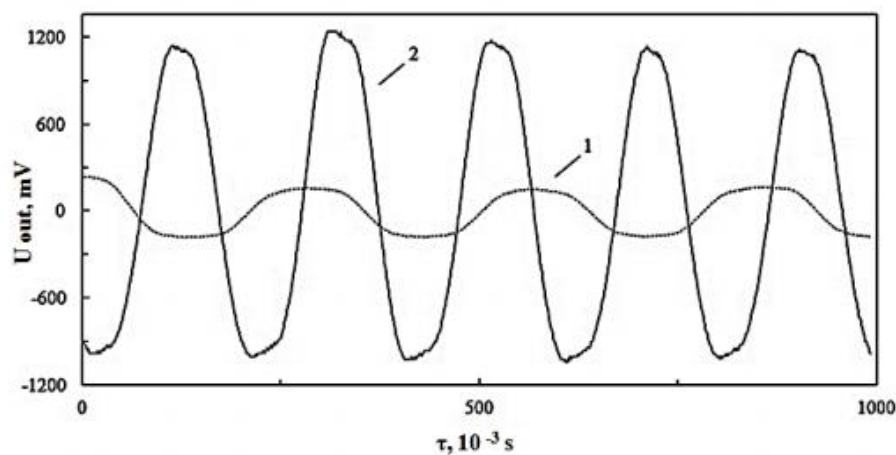


Figure 2. Graph of change in op-amp output voltage in time in the pulsed mode of irradiating the detector: 1 – without an irradiation source at a modulation frequency of 100 Hz, 2 – with an irradiation source at a modulation frequency of 60 Hz.

A comparison of the MCT detector and the thermal radiation source operation modes shows that the highest sensing power was achieved in the pulsed mode: the maximum amplitude of the voltage $U_{\max} = 1200$ mV, while in the continuous mode it is 1500 times smaller. Thus, the pulse mode of operation is most preferable, since high voltage values are achieved in this mode, which is especially important for studying the processes of mid-wavelength infrared transmission.

4. Results and discussion

As it was shown earlier, the radiation sensitivity of a CRT detector is significantly affected by the radiation transmission mode; therefore, in order to investigate the effect of a pulsed mode on the transmission of radiation through an optical fiber, it is necessary to compare the experimental results for two chemical compositions of infrared fibers at different pulse frequencies. Transmission of thermal energy by infrared fibers of various compositions in the pulsed mode was studied on $\text{AgCl}_{0.25}\text{Br}_{0.75}$ and $\text{Ag}_{0.95}\text{Tl}_{0.05}\text{Br}_{0.95}\text{I}_{0.05}$ fibers with a diameter of 1.12 mm, length of 150 mm. Initially, the spectral transmittance characteristics (figure 3) were obtained for the optical fibers under study using the IR -Fourier spectrometer IR-Prestige 21 Shimadzu.

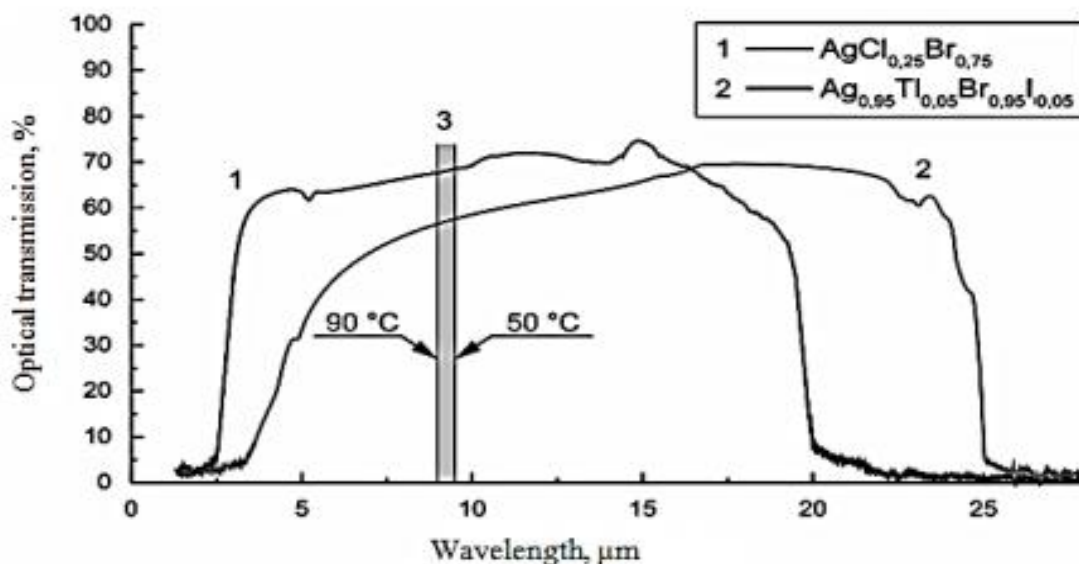


Figure 3. Spectral transmission characteristics of infrared fibers: 1 – $\text{AgCl}_{0.25}\text{Br}_{0.75}$, 2 – $\text{Ag}_{0.95}\text{Tl}_{0.05}\text{Br}_{0.95}\text{I}_{0.05}$, 3 – Peltier's element.

From the obtained spectral characteristics it can be seen that the infrared optical fibers have a high percentage transmittance over a broad spectral region including the analyzed mid -wavelength infrared range (7 - 9 microns). To study the transfer of heat radiation in a pulsed mode optical fiber placed between the modulator and receiver (see. figure 1), the radiation was transmitted from the source – the Peltier's element, and the modulation frequency was 60 Hz. The MCT detector operated in a linear mode depending on the oscillation frequency of the voltage exiting the op – amp from the rotational speed of the impeller. The results of the measurements are shown in figure 4.

Comparing maximum values of the pulsed voltage conduction modes infrared fibers of different compositions shows contrast by 15%. So, for the composition $\text{AgCl}_{0.25}\text{Br}_{0.75}$ $U_{\text{out}} = 11.2$ mV, and for the composition $\text{Ag}_{0.95}\text{Tl}_{0.05}\text{Br}_{0.95}\text{I}_{0.05}$ $U_{\text{out}} = 9.5$ mV. Differences in the voltage values for the two optical fiber compositions are related to the spectral characteristics, as well as to their refractive indices and the Fresnel losses. For $\text{AgCl}_{0.25}\text{Br}_{0.75}$ fibers, the refractive index $n = 2.138$ at a wavelength of 8 μm , and, consequently, the Fresnel losses for the two interfaces are 26.3%.

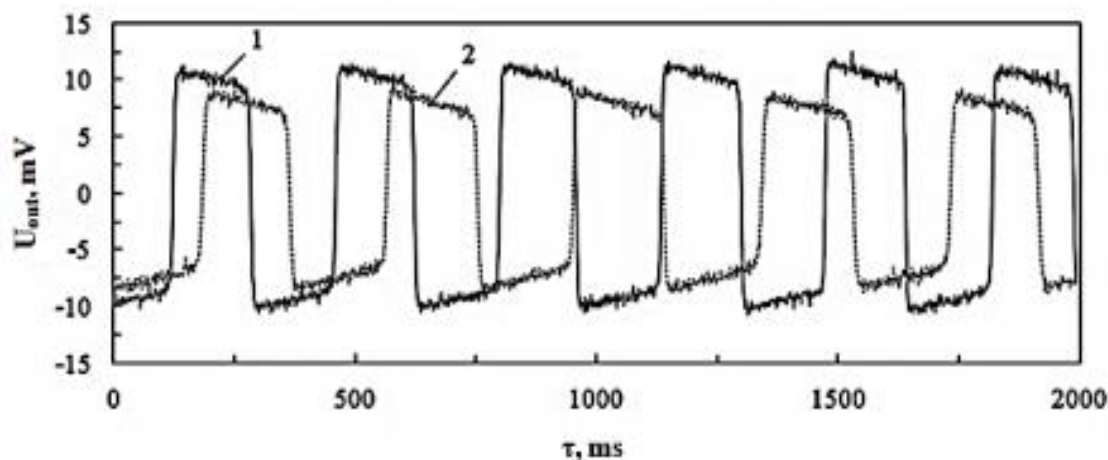


Figure 4. Spectral transmission characteristics of infrared fibers: 1 – $\text{AgCl}_{0.25}\text{Br}_{0.75}$, 2 – $\text{Ag}_{0.95}\text{Tl}_{0.05}\text{Br}_{0.95}\text{I}_{0.05}$, 3 – Peltier's element.

For the fiber of composition $\text{Ag}_{0.95}\text{Tl}_{0.05}\text{Br}_{0.95}\text{I}_{0.05}$, the refractive index is 2.239, Fresnel losses – 29.3% at a wavelength of 8 μm [4]. Thus, the use of an optical fiber with the chemical composition $\text{AgCl}_{0.25}\text{Br}_{0.75}$ will be the most effective in the pulsed mode of transmission of thermal radiation; in this mode, it is possible to obtain large values of the transmission of the IR wave in comparison with the $\text{Ag}_{0.95}\text{Tl}_{0.05}\text{Br}_{0.95}\text{I}_{0.05}$ fiber. However, the optical fiber of composition $\text{Ag}_{0.95}\text{Tl}_{0.05}\text{Br}_{0.95}\text{I}_{0.05}$ is advisable to apply in the wavelength range from 15 to 25 microns, since the transmission of the fiber of $\text{AgCl}_{0.25}\text{Br}_{0.75}$ composition is significantly reduced.

Acknowledgment

The research has been supported by the grants of President of the Russian Federation SP-2455.2018.1.

References

- [1] Korsakov A, Zhukova L, Korsakova E and Zharikov V 2014 *J. Crys. Growth* **386** 94
- [2] Lewi T and Katzir A 2012 *Opt. Lett.* **37** 2733
- [3] Israeli S and Katzir A 2011 *Opt. Mat.* **33** 1579
- [4] Korsakov A, Zhukova L and Vrublevsky D 2015 *Opt. Mat.* **50** 204